RESONANCES IN THE RADIOACTIVE CAPTURE OF PROTONS BY SILICON - 30

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MASTER OF SCIENCE
IN
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United States Naval Postgraduate School
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ABSTRACT

A sample of silicon enriched to 72.56% in the silicon-30 isotope was bombarded with protons ranging in energy from 200 to 1900 kev. Resonances in the $Si^{30}(p,\gamma)P^{31}$ reaction were detected at 367, 500, 625, 675, 760, 776, 830, 840, 896, 943, 955, 980, 991, 1000, 1008, 1084, 1092, 1157, 1178, 1203, 1214, 1297, 1308, 1322, 1326, 1353, 1398, 1408, 1426, 1491, 1500, 1521, 1528, 1608, 1671, 1680, 1704, 1781, 1811, 1815, 1821, 1836, 1879, 1895 kev.

This investigation presents in one report a continuous evaluation of the area from 200 - 1900 kev which previously was reported only in parts and by several authors. Conflicts in overlapping data have been clarified by a slight shift in the proton energy calibration utilized in a previous report.

ACKNOWLEDGEMENTS

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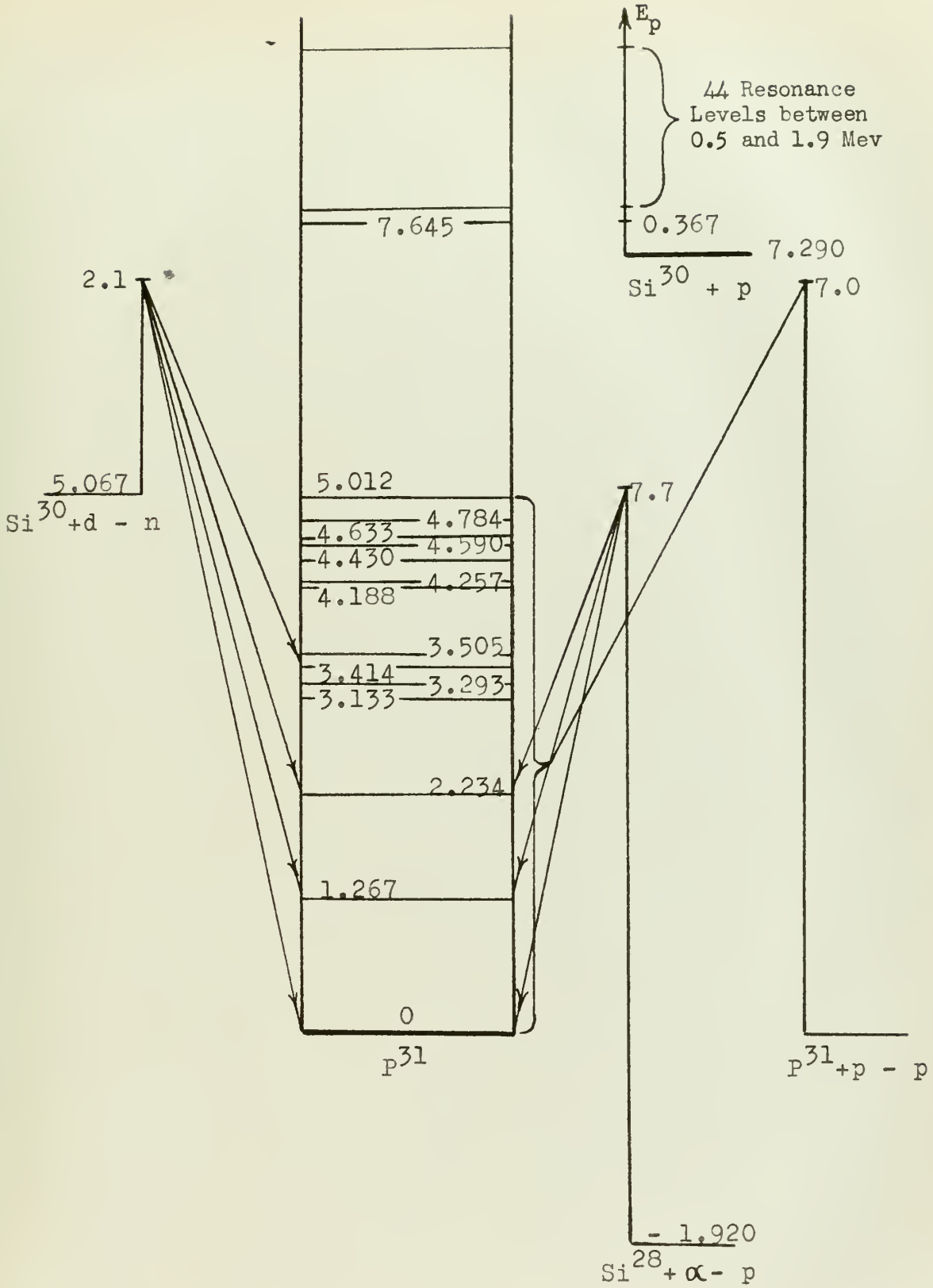


Figure 1.
Energy Level Diagram of P^{31}

A 2 Mev Van de Graaff electrostatic accelerator manufactured by the High Voltage Engineering Corporation of Cambridge, Massachusetts was used to provide protons with energies from 200 kev to 2 Mev. The accelerated protons, after leaving the accelerator traveled down an evacuated tube to a 25° magnetic analyzer. The magnetic analyzer provided the means of separating the ionized hydrogen particles into mass 1, 2, and 3, as well as, the means of determining the energies of these particles. Accurate measurements of the current passing through the coils of the magnetic analyzer were made by passing the current through a 0.1 ohm resistor and measuring the potential difference with a Leeds and Northrup potentiometer. The proton energies were calibrated to the magnet currents using the well-known resonances of lithium and fluorine which are present in this energy range. This technique made magnetic field determinations unnecessary.

Two and one-tenth meters beyond the center of the magnetic analyzer the energy width of the proton beam was defined by passing the beam through a slit 0.8 millimeters wide. Just beyond this slit, a solenoid-operated beam shutter was provided. The purpose of the shutter was to provide a mechanism by which it was possible to simultaneously commence or stop target bombardment, current integration, timing and counting without varying or otherwise altering the proton beam as received from the magnetic analyzer.

Intervening between the shutter and the target within the e-

vacuated tube was a silver wire loop, inserted to provide a Faraday cage. The lead to the loop was brought out of the tube through a Kovar glass seal to the negative terminal of a 300 volt battery in series with a 10 megohm resistor. The purpose of introducing the Faraday cage was to repel any negative ions formed in front of the cage by ionization of residual gas molecules and to prevent the escape of electrons from the target.

The target consisted of silicon-30 or, for calibration purposes, lithium fluoride evaporated onto a tantalum disk one centimeter in diameter and mounted on a silver wire target holder. The assembly consisting of the target and target holder was contained in a 7.8 centimeter long glass cap (0.5" O.D.) projecting from a target chamber constructed at the terminal end of the evacuated tube. The silver wire extending from the target chamber to the target was insulated with glass beads and glass tubing. The details of the target assembly are presented in Figure 2.

The necessary vacuum for the system was provided by the usual combination of diffusion and fore pumps. One such assembly was located at the beginning of the tube and another near the terminal end. Valves located at various points along the tube permitted changes or dissembly with minimum loss of vacuum. An interesting feature was introduced at the target end of the tube. The target chamber and the target were separated from the main column by a valve which followed the last diffusion-fore pump combination. In addition, the target chamber was provided with an outlet which could be attached to an auxiliary vacuum system. Thus, the target chamber and target

could be cut-off from the main system, the target changed, auxiliary pump temporarily attached and the system reopened in a matter of minutes without introducing a significant loss of vacuum.

A two-inch diameter, well-type, thallium-activated sodium iodide crystal mounted on a Dumont 6292 photomultiplier tube was used to measure the gamma-ray yield. The technique of enclosing the target in a projecting glass cap simplified the use of the well-type crystal. The signals from the photomultiplier tube were amplified and counted by a scaler. The silver wire to the target permitted the target to be connected electrically to a current integrating circuit to provide consistant target exposure. In addition, a relay of the integrating circuit was connected to a count switch of a decimal scaler and to a timer. A complete block diagram of the detection equipment is presented in Figure 3.

A proton energy resolution of about 0.2 percent at one Mev was stated to be possible by the manufacture. Repeated determinations made previously[11] have verified this claim. During our investigation some resonance peaks were measured with half value widths of approximately 2 kev indicating the above claims and verifications are well founded.

As expected there was a drift in the magnetic current analyzer; however, the extent of this drift was exceedingly small. The drift was never observed to exceed 0.0005 amperes (0.82 kev) and most often was contained to less than 0.0001 amperes. In view of the extent of proton energy resolution and variation of magnetic analyzer current, the data presented herein is be-

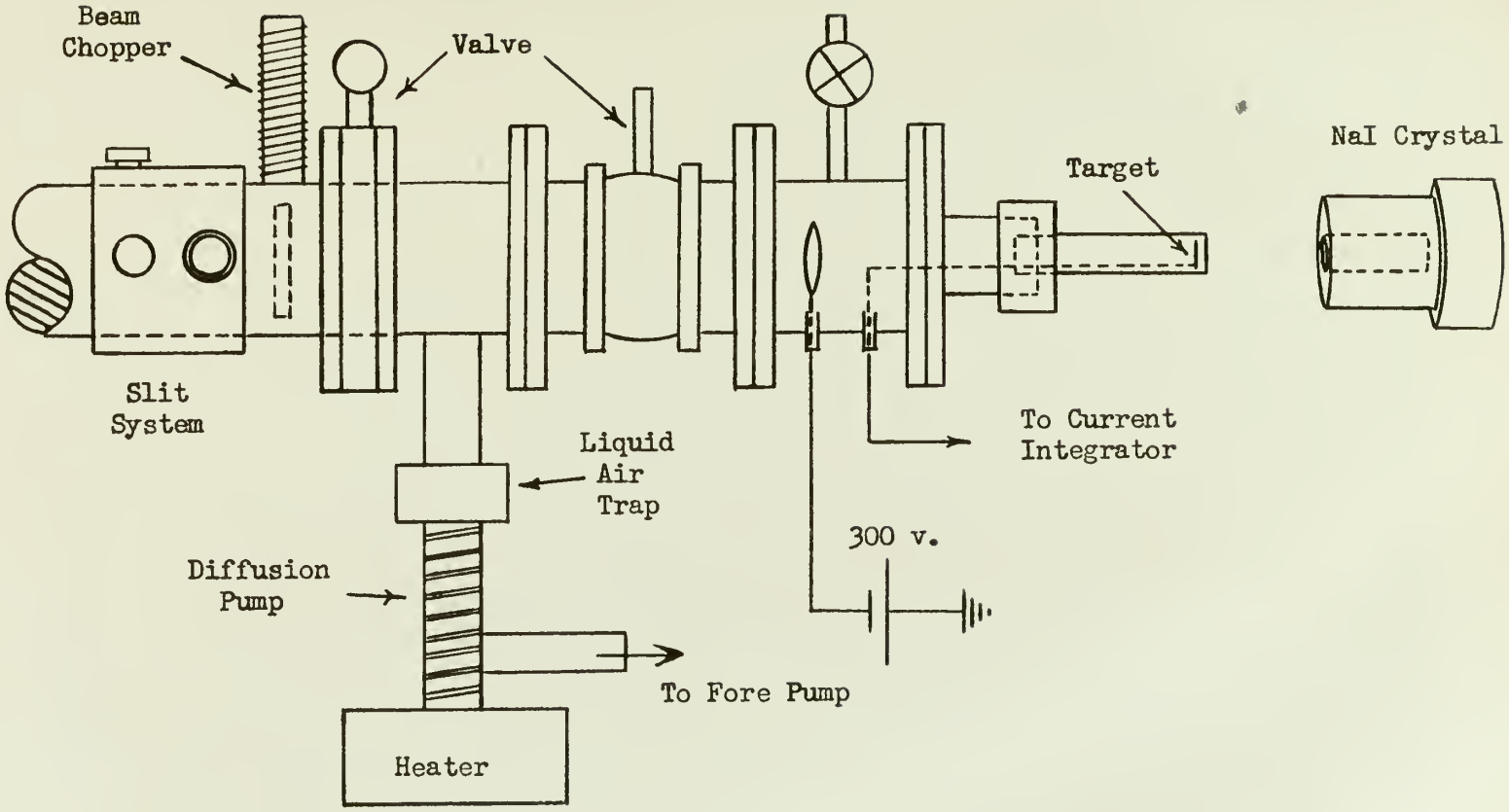


Figure 2.

Target Assembly

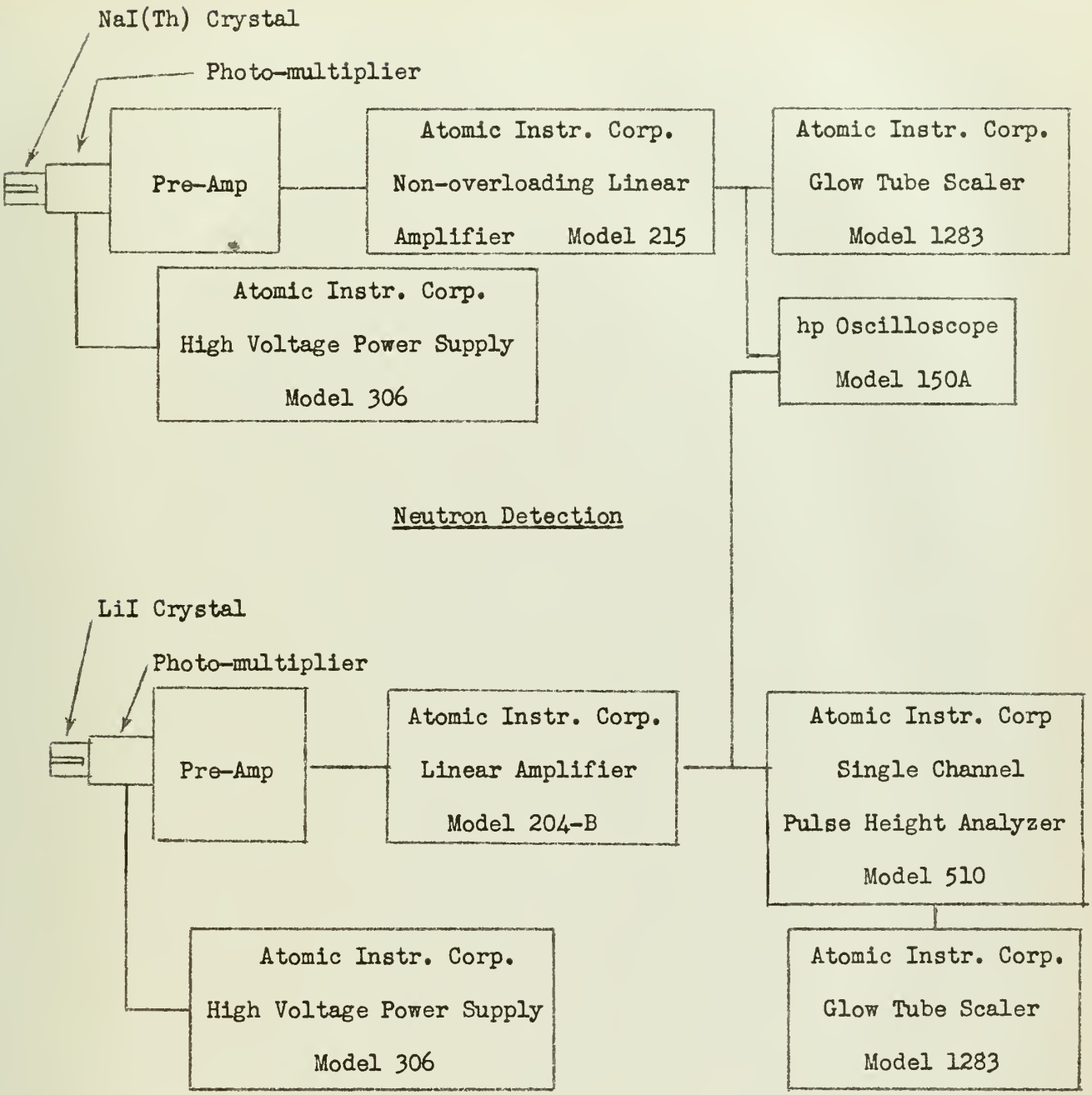


Figure 3.

Block Diagram of Detection Equipment

lieved to be accurate within a standard deviation two kev assuming the validity of lithium fluoride resonances reported by Zjzenberg and Lauritsen[12].

The operating of the project required the use of two people. One was required to operate the console of the Van de Graaff generator to provide the proper proton energies and record the magnetic analyzer current. The magnet was cycled slowly twice before each operation and the magnet current was always advanced-never reduced. The purpose of these procedures was to provide standardization of technique and to reduce hysteresis effect. Each reading from the Leeds and Northrup potnetiometer was verified against a standard cell. The second operator, who recorded the data, was located near the target chamber and operated the detection equipment and the current integrator.

The first examination of the 1 - 1.9 Mev range was made with targets of silicon-30 showing rather heavy fluorine contamination. Another run was made through this area with targets of lithium fluoride void of silicon-30. A third run was made with targets of silicon-30 that had exceptionally little fluoride contamination. Lastly, a blank target (uncoated tantalum) was run in this area. Observations of various resonance peaks and their relative yields for the different targets made it possible to possible to positively identify the specific peaks and interpret the results presented in this report.

RESULTS

Figure 4 presents the relative gamma yield for protons with bombarding energies ranging from 200 to 1900 kev. The contributions due to background, determined by using blank targets, has been subtracted. Table 2 lists the resonances and relative gamm-ray yields for these proton energies with constant slit width.

TABLE 2

RESONANCES IN SILICON-30

Proton Energy (kev)	Relative Yield
367	4.5
500	4.6
625	39.8
675	1.0
760	2.1
776	4.7
830	3.2
840	1.2
896	1.7
943	4.4
955	1.2
980	6.4
991	0.8
1000	0.9
1008	1.1
1084	1.4

TABLE 2 (Cont.)

RESONANCES IN SILICON-30

Proton Energy (kev)	Relative Yield
1092	2.0
1157	1.7
1178	2.4
1203	8.1
1214	2.4
1297	1.4
1308	2.8
1322	0.5
1326	7.5
1353	0.7
1398	10.8
1408	10.2
1426	0.5
1491	10.7
1500	5.0
1521	7.4
1528	1.2
1608	1.5
1671	1.1
1680	1.8
1704	3.7
1781	7.8
1811	2.3
1815	3.7
1821	3.5

TABLE 2 (Cont.)

RESONANCES IN SILICON-30

Proton Energy (kev)	Relative Yield
1836	5.1
1879	12.8
1895	3.9

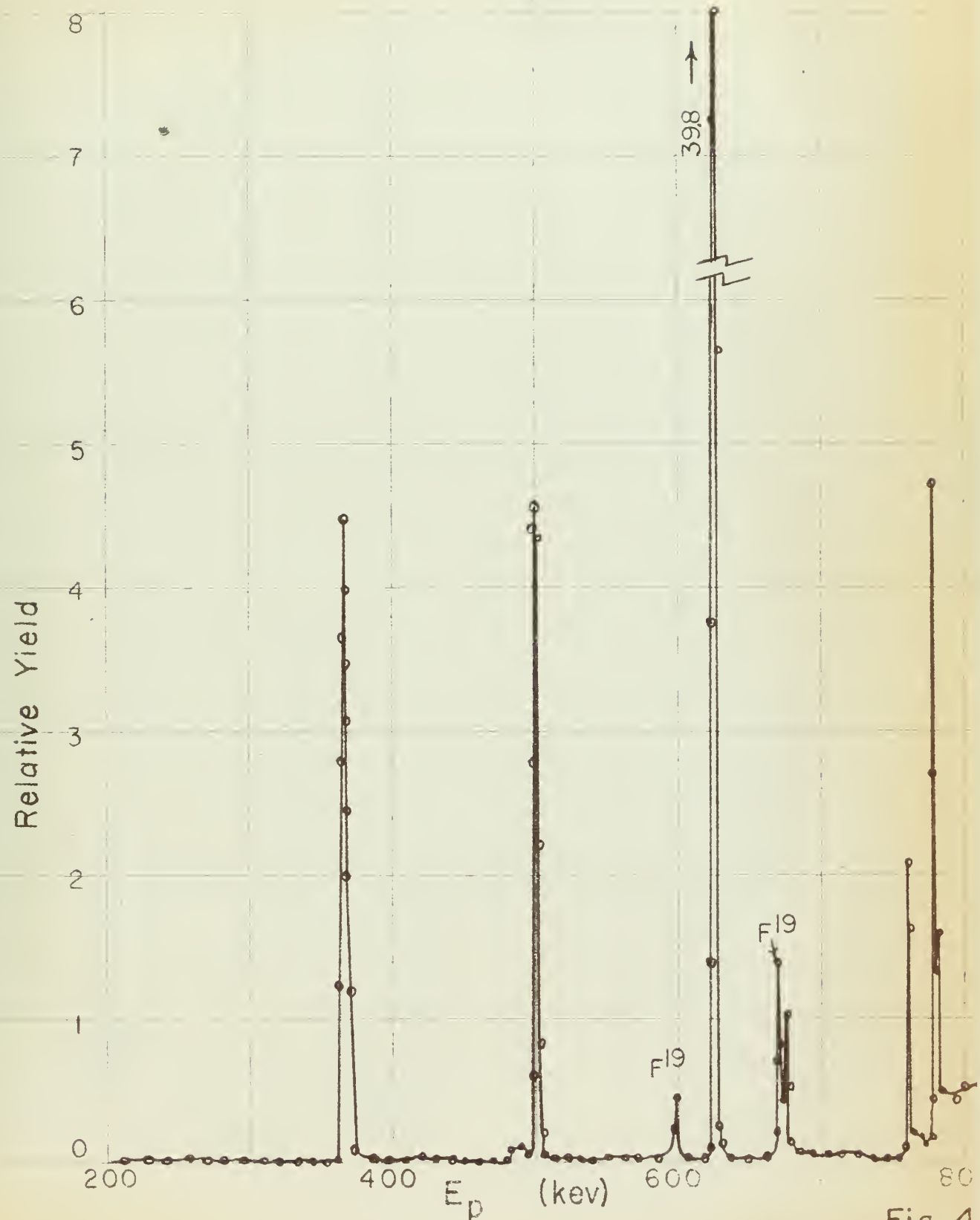
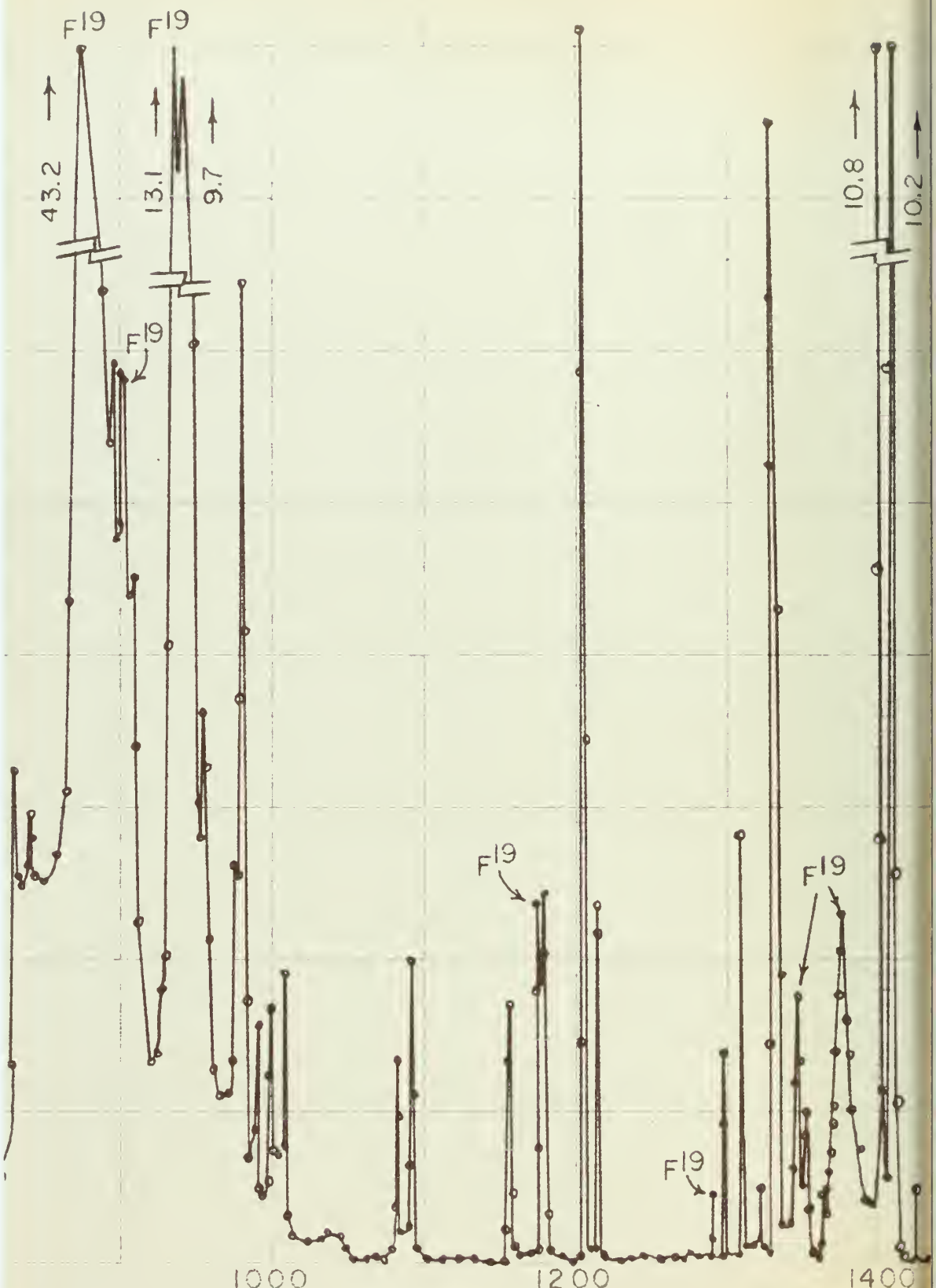


Fig. 4

CROSS SECTION


12.8
Si29
1600
1800
2000



- Gamma Yield for $Si^{30}(p,\gamma)P^{31}$ Reaction

All resonances reported by Broude, et al (500, 625, 576, 760, 775, 840, 955, 980, 995 and 1000 kev) were confirmed except that the resonance reported to be at 995 kev was found to occur at 991 kev. In addition resonances, not reported by these authors, were found to occur at 830, 896, and 943 kev. Tsytko and Autuf'ev reported resonances at 831, 895 and 940; however, resonances at 619, 717, 753 and 800 also reported by this group were not found.

It will be noted in comparing the resonances located in the area from 1000 to 2000 kev with those reported by Green and Wiseman that all except three resonances were located. No evidence of a silicon-30 resonances at 1263 or 1303 kev could be found and only an indication of a possible resonance at 1188 kev was detected. Significant variations in a few cases appear in the energy at which the reactions occur. The differences between the energy reported here and those previously reported can be reconciled. A careful review of the Green and Wiseman data revealed that the accuracy of their data was influenced by the use, as a calibration point, of a fluorine resonance reported by them as accuring at 1283 kev. Recently published data[12] report this resonance to be located at 1290 kev and which the data in this report also confirms. Shifting the calibration curve presented by Green and Wiseman to the correct value for this fluorine resonance will account for the deviations noted. The calibration curve used for this study is presented in Figure 5.

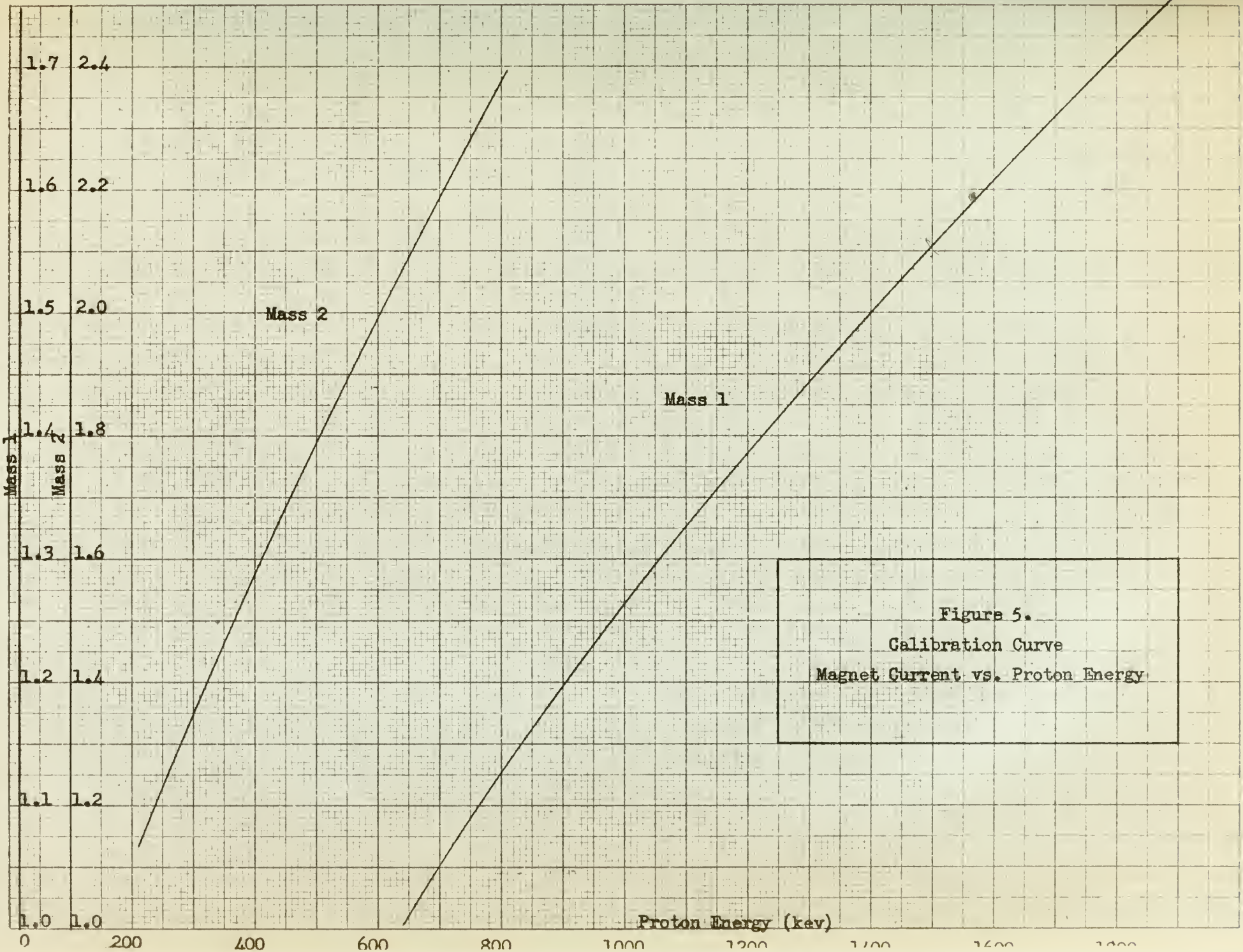


Figure 5.
Calibration Curve
Magnet Current vs. Proton Energy

No new resonances or deviations from the published values of the location and relative gamma yields were noted for the area extending from 200 to 500 kev.

The broad rise in gamma-ray yield occuring in the neighborhood of 1600-1800 kev is believed to be due to silicon-28. The targets used in this investigation contained 26% silicon-28 and a strong broad resonance due to this isotope would be expected to be found.

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APPENDIX I

REPORTED RESONANCES IN SILICON

Natural Si

326(4)(10)
367(4) 369(10)
413(2) 414(4)(5)(10)
497(2) 499(4) 500(5) 501(10)
619.5(9) 622(5)(10)
675(5)
698(5) 697(10)
703(5)
717(9)
732(5)
753(9)
760(5)
775(9) 778(5) 776(10)
800(9)
831(9)
836(10)
895(9)
940(9)
944(5) 943(10)
957(10)
980(9) 979(10)
989(5)
1202(10)
1205(10)
1291(10)
1327(10)
1394(10)
1520(9)
1618(9)
1635(9)
1647(9)
1663(9)
1680(9)
1699(9)
1774(9)
1810(9)
1849(9)
1879(9)

REPORTED RESONANCES IN SILICON

Si^{30}

367(4)
499(4) 500(8)
619.5(9)
625(8)
675(8)
717(9)
753(9)
760(8)
775(9)(8)
800(9)
831(9)
840(8)
895(9)
940(9)
945(11)
955(8)
980(9)(8)
989(11)
995(8)
1000(8)
1108(11)
1178(11)
1188(11)
1214(11)
1221(11)
1263(11)
1297(11)
1303(11)
1307(11)
1329(11)
1353(11)
1397(11)
1406(11)
1425(11)
1491(11)
1498(11)
1519(11)
1526(11)
1606(11)
1667(11)
1675(11)
1701(11)
1777(11)
1811(11)
1814(11)
1821(11)
1836(11)
1882(11)
1897(11)

Si^{29}

326(6)
414(6)
638(6)(9)
731(6)(9)
918(6)(9) 920(11)
957(6)(9) 960(11)
1309(11)
1334(11)
1479(11)
1515(11)
1648(11)
1671(11)
1692(11)
1752(11)
1777(11)
1857(11)

APPENDIX II

PREPARATION OF TARGETS

Silicon-30 and lithium fluoride were plated upon small tantalum disks using a standard vacuum plating technique. Specifically, the technique involved placing a strip of tungsten, with a small depression in the center to hold the material to be evaporated, between two electrodes and applying sufficient current to raise the temperature to the point where evaporation of the material in the depression took place. Attached to the underside of a metal table, placed over the electrodes, were one centimeter in diameter, 5 mil thick disks onto which either silicon-30 or lithium fluoride was evaporated. The electrodes and disks were enclosed in a bell jar which was evacuated to a pressure of approximately 10^{-6} mm Hg before the process of evaporation commenced.

The silicon-30, which had been electromagnetically separated at the Oak Ridge National Laboratory, was in the form SiO_2 and contained 72.56% of silicon-30, 25.90% of silicon-28, and 1.56% of silicon-29. Meticulous care was excerised to prevent unnecessary contamination. All materials were cleaned with detergents, rubbed with extremely fine sand paper or crocus cloth, washed with acetone and finally rinsed with c.p. alcohol. Before the targets were exposed for plating, the system was evacuated and the tungsten connecting the electrodes was heated white hot to eliminate from the surface all volatile materials that would evolve during the plating process. Two separate vacuum plating systems were used. One for silicon plating and

the other for lithium floride plating. This procedure is recommended if it is desired to keep fluoride contamination on the silicon targets reasonably low.